THE AM UMBRELLA ANTENNA

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ABSTRACT

One of the greatest limiting factors in locating an AM broadcast tower is the significant amount of acreage occupied by the buried radials. The authors describe a novel method of feeding a grounded tower which overcomes this difficulty, since essentially no land is required for the earth connection. Computer-predicted values of radiated electric-field intensity are competitive with those generated by conventional techniques. A scale model has been constructed, and measured results are discussed in comparison with computed values.

INTRODUCTION

The goal of this project was to find a way to modify pre-existing multiple-use communications towers, located on sites with restricted amounts of surface area, so they could also serve as medium-wave broadcast antennas. The tower under study here is a generic self-supporting three-legged tapered design, with both horizontal and diagonal cross-members. The tower height is 300 feet, with a face width of 28 feet at the bottom, tapering to 4 feet at the apex. Two different operating frequencies were used - 1500 kHz, where the tower height is nearly 0.46 wavelength, and 750 kHz, at which point the tower is only 0.23 wavelengths tall.

Computer-modeling was performed using the EZNEC pro [1] software package, with a NEC-4 calculating engine. For simplicity, the diameter of all conductors was specified at 0.25 inches, and they were assumed to be composed of zinc, since most towers are constructed of zinc-coated (galvanized) steel.

BASIC CONCEPT

The antenna system, which has been dubbed the "AM Umbrella," is configured by suspending three outrigger "umbrella" wires from the tower, at some distance above its base. These umbrella wires are spaced uniformly around the tower, at 120 degree azimuth intervals, sloping outward and downward toward the ground. All three of the umbrella wires have the same length, the same slope angle, and are attached at the same relative locations on the tower. The inner (upper) ends of the umbrella wires are anchored to the tower structure, but are electrically insulated from it. These three umbrella wires are "hot," and are driven against the grounded tower. In practice, short equal-length insulated "pig-tail" wires extend from the inner end of each umbrella wire to a junction-box. Here, they are connected to the center conductor of the transmission line, which is carried up the tower (along one leg) to the feed-point, which is situated on the central axis of the tower. The outer conductor of the transmission line is bonded solidly to the tower's metallic framework at this location. *Figure 1* illustrates the 300-foot self-supporting tower, with a typical "AM Umbrella" antenna installation.

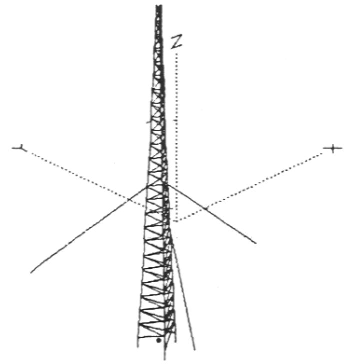

Figure 1

REFERENCE ANTENNAS

A number of different antennas were examined, in order to serve as standard references to which the performance of the AM Umbrella could be compared. First, a simple base-fed uniform-cross-section quarter-wave vertical monopole was modeled over perfectly-conducting earth, to provide the attenuated electric-field strength data. Next, the same monopole was placed over real earth (with soil conductivity of 0.005 Siemens/meter and dielectric constant of 13) and a buried ground system consisting of 120 quarter-wave radials was added. Third, the 300-foot free-standing tapered tower (described earlier) was modeled over perfect earth. Here, all three legs were base-fed, and no umbrella wires were included. Finally, the same self-supporting tower was driven against a 120-buried-radial ground system, immersed in the same type of soil mentioned above. All four of the reference configurations were modeled at both frequencies of interest, 1500 kHz and 750 kHz, and the results are listed in Table I.

Table I. Electric-field Intensity Values for the Various Reference Antennas Described in the Text.

Tower Type	Ground System	Freq. (kHz)	Electric-field Strength (mV/m)
Uniform Cross-section (quarter-wave)	Perfect Conductor	1500	311.6
Uniform Cross-section (quarter-wave)	Perfect Conductor	750	310.9
Uniform Cross-section (quarter-wave)	Real Earth, 120 radials	1500	281.0
Uniform Cross-section (quarter-wave)	Real Earth, 120 radials	750	296.3
Tapered, Self-supporting (300-foot)	Perfect Conductor	1500	359.7
Tapered, Self-supporting (300-foot)	Perfect Conductor	750	305.6
Tapered, Self-supporting (300-foot)	Real Earth 120 radials	1500	324.5
Tapered, Self-supporting (300-foot)	Real Earth, 120 radials	750	289.0

The field-intensity value in each row is the vertical component predicted by the computer, calculated at ground level at a distance of one kilometer, with a power input of one kilowatt.

From this table, one can see that the unattenuated field intensity produced by a conventional quarter-wave monopole is just over 300 millivolts per meter, at either operating frequency. When installed over a classic 120-buried-radial ground system, the efficiency of both systems decreases slightly,

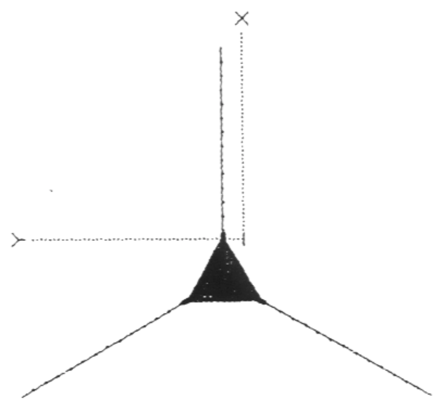

Figure 2

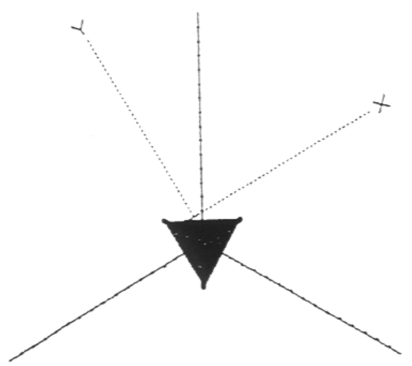

Figure 3

although the lower-frequency antenna works a bit better, as would be expected. In the case of the free-standing 300-foot tapered tower, the fields generated over either type of ground are larger at 1500 kHz than at 750 kHz, because the electrical height of the tower is twice as great at the higher frequency.

AM UMBRELLA COMPUTER MODELS AT 1500 kHz

It was expected that the AM Umbrella method would work best if the feed-point was located about a quarter-wavelength below the top of the tower. At 1500 kHz, this distance is 163.94 feet, which would place the feed-point at a height of 136.06 feet above the ground. The nearest tower-leg/cross-member junctions in our generic 300-foot-tower model were at heights of 132 and 144 feet, so both of these elevations were utilized (one at a time) for the initial series of tests. Each umbrella wire was anchored to a tower leg, with the wires extending downward toward the ground at azimuths of 0, 120, and 240 degrees as shown on *Figure 2*. Later, the upper anchor-points for the umbrella wires were moved to the middle of the tower faces, on the horizontal crossmembers. *Figure 3* gives a plan view of this arrangement.

For the computer model, the three pig-tail wires and central junction-box were omitted. Instead, three separate sources were incorporated, one at the inner end of each umbrella wire. Slope-angles of both 45 and 60 degrees were investigated to determine the impact of changes in this parameter. (If a tower site is very small, then steeply-sloping umbrella wires might be needed in order to fit the entire antenna system within a limited area.) The length of the umbrella wires was also varied, from one-quarter to three-sixteenths to one-eighth wavelength.

Table II displays the outcome of these computer simulations, conducted at 1500 kHz over perfectly-conducting earth. To summarize, changing either the anchor height, the slope-angle, or the length of the umbrella wires had very little impact upon the magnitude of the unattenuated electric field. When the anchor-points were moved from the legs of the tower to the faces, the signal strength diminished slightly in every case, but again the decrease was small. Notice that several lines in the table have no data: when quarter-wave umbrella wires were sloped downward at a 60-degree angle, their lower ends extended either very close to, or actually intersected, the ground. For all the combinations tested, the radiation patterns generated by the AM Umbrella are highly circular, with field magnitudes well above 300 millivolts per meter.

Table III shows the results for the same AM Umbrella antenna systems that were described in the preceding paragraph, but now our 300-foot tower is situated over real earth, with a single eight-foot ground rod penetrating into the soil at the bottom of each leg. The radiated fields are down by only 1.3 to 1.6 dB when compared to the perfect-earth scenario, but still above 300 millivolts per meter for the most part. As before, leg-mounted umbrella wires generate somewhat higher electric-field intensifies than those which are attached to the tower faces. This time, however, anchoring the umbrella wires at the 144-foot level, rather than at 132 feet, yielded a consistent advantage of about 7 to 10 mV/m.

It is likely that the "ground connection" for a real tower would be more extensive than just three eight-foot rods. The base of each tower leg would probably be encased in a concrete footer and tied to an extensive system of steel reinforcing rods or "re-bar." Further, extra driven ground rods might also be installed for lightning protection. When the length of the three ground rods in the computer model was increased from eight to twelve feet, the magnitude of the radiated fields increased in every case which was examined, so the values listed in Table III may be conservative.

AM UMBRELLA COMPUTER MODELS AT 750 kHz

Although the height of our 300-foot tower is less than a quarter-wavelength at 750 kHz, it was decided to repeat the entire test sequence outlined above at this lower frequency. Every parameter is exactly the same as before, including the physical lengths of the umbrella wires. (Of course, their electrical lengths are now reduced to either one-eighth, three thirtyseconds, or one-sixteenth of a wavelength.) When modeled over perfect earth, the resulting unattenuated field values, as predicted by the computer, are provided in Table IV. Longer umbrella wires appear to work best, and a 45-degree down-slope is preferable to the steeper 60-degree angle. As usual, anchoring the umbrella wires to the legs of the tower is superior to the face-mounting scheme, and attaching them higher on the tower also yields a bit of an edge. Interestingly, all of the signal-strength values reported in this table exceed the FCC-specified minimum standard of 282 mV/m/kW at one kilometer.

Table V shows what happens when the 750 kHz AM Umbrella antennas are installed over real earth, with one eight-foot ground rod driven at the base of each tower leg. The radiated fields are much weaker now, roughly 4.5 dB lower than was calculated for the same antenna over a perfect conductor. All of the field-intensity values fall in the range of 170 to 180 millivolts per meter, but would be higher if the ground rods were longer or more numerous.

At this time, it was decided to raise the attachment point for the umbrella wires to the top of the 300-foot tower, since its height was only 0.23 wavelength. As usual, two different anchor locations and two slope angles were examined, but now it was possible to utilize longer umbrella wires: one-eighth, three-sixteenths, and one-quarter wavelength.

The results of this computer-modeling exercise are displayed in Table VI, for the AM Umbrella antenna installed over perfect earth. Now all of the unattenuated field intensities are above the

300 mV/m level. Once again, face-mounting of the upper ends of the umbrella wires is slightly inferior to leg-anchoring. Shorter umbrella wires are actually better than longer ones, in most cases, although the differences in performance are negligible.

Table VII gives the outcome for the same group of antennas when installed over real earth, using only a set of three eight-foot driven rods for the ground system. Several configurations can still produce fields in excess of 200 millivolts per meter, with the strongest signals coming from those versions with eighth-wave umbrella wires whose upper ends are anchored to the tower legs.

SCALE-MODEL TESTS

Additional development work was performed in relation to an actual tower site in the southeastern part of the US. Here, it was desired to modify an existing 300-foot Rohn SSVMW tower to enable AM-broadcast operation at a frequency of 1550 kHz. Due to site constraints, it was necessary that the EZNEC computer model incorporate three face-mounted eighth-wave umbrella wires, positioned at the 150-foot level, with a very steep down-slope angle of about 66 degrees. The unattenuated field for this antenna was calculated to be about 355 millivolts per meter, versus 306 mV/m for a conventional quarter-wave uniform-cross-section vertical monopole.

Physical models of the Rohn SSVMW tower and two quarter-wave monopoles were assembled from brass rod and tubing. These models were built to a scale of 69.6:1, so 1550 kHz corresponds to 107.9 MHz. The tower model is 55" tall and 6.3" wide at the base, with legs, cross-members, and diagonals constructed to duplicate the configuration of wires that was input to the computer. *Figure 4* is a photo showing most of the tower model, the three sloping eighth-wave umbrella wires, and the N connector at the feed-point.

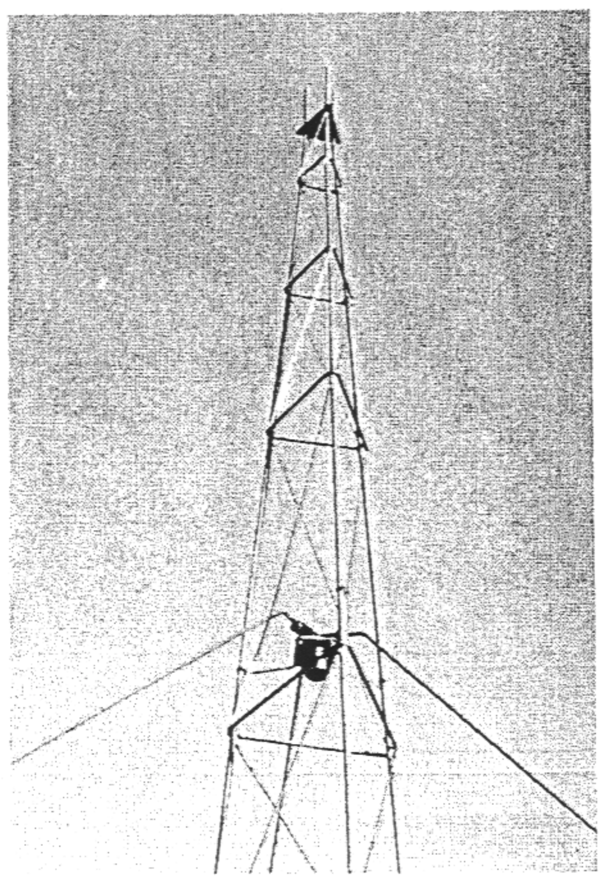
Figure 4

Field-strength tests were conducted at the Communications Technologies offices in southern New Jersey. One of the quarter-wave verticals was used as the "receive" antenna, and was connected to the input of a Sencore FS73 synthesized field-strength meter through a short length of double-shielded coax. Measurement points were marked on a tarred road surface at ten-foot intervals, beginning at the receive antenna and extending away from it for a distance of 150 feet. The "antenna under test," either the AM Umbrella or the second quarter-wave monopole, was then placed at each marked location and driven by a QEI 675 exciter via a Bird 43 wattmeter. Readings for both forward and reflected power were taken at each measurement point, as well as the value of the received electric-field intensity. All data was collected within a 90-minute period to assure that no environmental effects would influence the results.

Analysis of the measurement data showed that the average field intensity radiated by the AM Umbrella antenna was 0. 5 dB greater than for the reference quarter-wave vertical. In the course of the information-gathering campaign, additional tests were run to confirm the computer predictions. The AM Umbrella scale model was rotated about the tower axis to determine if there was any difference in field intensity off the ends of the umbrella wires, as compared to a point midway between them, and no change could be discerned.

FUTURE WORK

Computer modeling indicates that the AM Umbrella antenna concept also performs well with uniform-cross-section guyed towers of varying heights, and this topic will be the subject of further investigations.

CONCLUSIONS

This paper has discussed a simple technique for adding medium-wave transmitting capabilities to free-standing grounded communications towers. Computer exercises have predicted that the values of electric-field intensity produced by the "AM Umbrella" are competitive with those generated by conventional installations, and scale-model testing has confirmed the radiation efficiency of the self-supporting tower that was studied.

A full-size AM Umbrella antenna is presently in operation on a tapered, free-standing, tower but no detailed performance data is yet available. As stated above, EZNEC analysis indicates that the AM umbrella concept can also be applied to grounded, uniform cross section, guyed towers. The first such installation has been completed and is located in central Florida. Measurements submitted to the Federal Communications Commission indicate that this antenna system is operating with an unattenuated inverse field strength at one kilometer equal to that of a base insulated tower, of the same electrical height, mounted above a ground system consisting of 120 equally spaced, quarter wave length, buried copper radials.

REFERENCES

1. EZNEC pro is available from Roy Lewallen, W7EL, PO Box 6658, Beaverton, OR 97007.

2. Al Christman and Clarence M. Beverage, "An Innovative AM Radiator Design Employing Radiating Guy Wires, and AM Antenna System Technology Update," Proceedings of the 1997 NAB Broadcast Engineering Conference, April 1997, pages 297-305.

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Table II. Electric-field Intensity Values for "AM Umbrella" Antenna on Self-supporting Tower when Situated over Perfect Earth. Tower Legs are Located at Azimuth Angles of 0, 120, and 240 degrees. Transmit Frequency is 1500 kHz.

	Umbrella-Wire Attributes			Electric-field
Anchor Location	Anchor Height (ft)	Down-slope Angle (deg)	Length (Lambda)	Strength (mV/m)
Leg	132	45	0.25	368.18, 370.27
"	"	"	0.1875	373.41, 374.05
"	"	"	0.125	373.48, 373.60
Leg	132	60	0.25	*
"	"	"	0.1875	367.99, 368.39
"	"	"	0.125	368.18, 368.26
Leg	144	45	0.25	369.50, 371.41
"	"	"	0.1875	374.01, 374.60
"	"	"	0.125	373.94, 374.04
Leg	144	60	0.25	**
"	"	"	0.1875	369.07, 369.41
"	"	"	0.125	369.21, 369.28
Face	132	45	0.25	361.14, 359.33
"	"	"	0.1875	364.83, 364.25
"	"	"	0.125	365.78, 365.67
Face	132	60	0.25	*
"	"	"	0.1875	357.88, 357.56
"	"	"	0.125	359.89, 359.81
Face	144	45	0.25	362.32, 360.65
"	"	"	0.1875	365.22, 364.70
	"	"	0.125	365.54, 365.44
Face	144	60	0.25	**
"	"	"	0.1875	358.92, 358.61
"	"	"	0.125	360.19, 360.12

The field-intensity values in each row are the vertical components predicted by the computer for azimuth angles of 0 and 60 degrees, respectively, calculated at ground level at a distance of one kilometer, with a power input of one kilowatt.

* = Quarter-wave radials are not used, because they are so long they would intersect the ground.

** = Quarter-wave radials are not used, because they are so long they would extend to within two feet of ground level.

Table III. Electric-field Intensity Values for "AM Umbrella" Antenna on Self-supporting Tower with Three 8-foot Ground Rods, when Situated over Real Earth. Tower Legs are Located at Azimuth Angles of 0, 120, and 240 degrees. Transmit Frequency is 1500 kHz.

	Umbrella-Wire Attributes			Electric-field
Anchor Location	Anchor Height (ft)	Down-slope Angle (deg)	Length (Lambda)	Strength (mV/m)
Leg	132	45	0.25	305.66, 309.39
"	"	"	0.1875	312.18, 313.71
"	"	"	0.125	314.24, 314.74
Leg	132	60	0.25	*
"	"	"	0.1875	304.43, 305.17
"	"	"	0.125	309.56, 309.82
Leg	144	45	0.25	315.05, 318.70
"	"	"	0.1875	321.01, 322.50
"	"	"	0.125	322.57, 323.05
Leg	144	60	0.25	**
"	"	"	0.1875	314.66, 315.38
"	"	"	0.125	318.19, 318.43
Face	132	45	0.25	299.89, 296.64
"	"	"	0.1875	304.79, 303.52
"	"	"	0.125	308.02, 307.60
Face	132	60	0.25	*
"	"	"	0.1875	295.09, 294.48
"	"	"	0.125	302.74, 302.52
Face	144	45	0.25	309.82, 306.61
"	"	"	0.1875	313.81, 312.53
"	"	"	0.125	315.51, 315.11
Face	144	60	0.25	**
"	"	"	0.1875	305.65, 305.04
"	"	"	0.125	310.44, 310.23

The field-intensity values in each row are the vertical components predicted by the computer for azimuth angles of 0 and 60 degrees, respectively, calculated at ground level at a distance of one kilometer, with a power input of one kilowatt.

* = Quarter-wave radials are not used, because they are so long they would intersect the ground.

** = Quarter-wave radials are not used, because they are so long they would extend to within two feet of ground level.

Table IV. Electric-field Intensity Values for "AM Umbrella" Antenna on Self-supporting Tower when Situated over Perfect Earth. Tower Legs are Located at Azimuth Angles of 0, 120, and 240 degrees. Operating Frequency is 750 kHz.

	Umbrella-Wire Attributes			Electric-field
Anchor Location	Anchor Height (ft)	Down-slope Angle (deg)	Length (Lambda)	Strength (mV/m)
Leg	132	45	0.125	300.87, 300.94
"	"	"	0.09375	298.27, 298.30
"	"	"	0.0625	289.18, 289.20
Leg	132	60	0.125	*
"	"	"	0.09375	296.98, 297.00
"	"	"	0.0625	284.45, 284.46
Leg	144	45	0.125	301.81, 301.87
"	"	"	0.09375	299.76, 299.78
"	"	"	0.0625	292.01, 292.02
Leg	144	60	0.125	**
"	"	"	0.09375	298.91, 298.93
"	"	"	0.0625	288.19, 288.19
Face	132	45	0.125	295.75, 295.69
"	"	"	0.09375	294.11, 294.09
"	"	"	0.0625	289.17, 289.16
Face	132	60	0.125	*
"	"	"	0.09375	290.56, 290.55
"	"	"	0.0625	283.28, 283.28
Face	144	45	0.125	296.05, 296.00
"	"	"	0.09375	294.64, 294.62
"	"	"	0.0625	290.07, 290.06
Face	144	60	0.125	**
"	"	"	0.09375	291.72, 291.71
"	"	"	0.0625	285.21, 285.21

The field-intensity values in each row are the vertical components predicted by the computer for azimuth angles of 0 and 60 degrees, respectively, calculated at ground level at a distance of one kilometer, with a power input of one kilowatt.

* = Eighth-wave radials are not used, because they are so long they would intersect the ground.

** = Eighth-wave radials are not used, because they are so long they would extend to within two feet of ground level.

Table V. Electric-field Intensity Values for "AM Umbrella" Antenna on Self-supporting Tower with Three 8-foot Ground Rods, when Situated over Real Earth. Tower Legs are Located at Azimuth Angles of 0, 120, and 240 degrees. Transmit Frequency is 750 kHz.

	Umbrella-Wire Attributes			Electric-field
Anchor Location	Anchor Height (ft)	Down-slope Angle (deg)	Length (Lambda)	Strength (mV/m)
Leg	132	45	0.125	179.88, 180.01
"	"	"	0.09375	180.38, 180.43
"	"	"	0.0625	176.69, 176.71
Leg	132	60	0.125	*
"	"	"	0.09375	178.10, 178.13
"	"	"	0.0625	173.18, 173.19
Leg	144	45	0.125	182.07, 182.18
"	"	"	0.09375	182.74, 182.78
"	"	"	0.0625	179.66, 179.68
Leg	144	60	0.125	**
"	"	"	0.09375	180.98, 181.00
"	"	"	0.0625	176.75, 176.75
Face	132	45	0.125	175.99, 175.89
"	"	"	0.09375	177.21, 177.17
"	"	"	0.0625	176.15, 176.14
Face	132	60	0.125	*
"	"	"	0.09375	173.29, 173.27
"	"	"	0.0625	171.73, 171.73
Face	144	45	0.125	177.87, 177.79
"	"	"	0.09375	179.05, 179.02
"	"	"	0.0625	178.02, 178.01
Face	144	60	0.125	**
"	"	"	0.09375	175.78, 175.76
"	"	"	0.0625	174.29, 174.28

The field-intensity values in each row are the vertical components predicted by the computer for azimuth angles of 0 and 60 degrees, respectively, calculated at ground level at a distance of one kilometer, with a power input of one kilowatt.

* = Eighth-wave radials are not used, because they are so long they would intersect the ground.

** = Eighth-wave radials are not used, because they are so long they would extend to within two feet of ground level.

Table VI. Electric-field Intensity Values for "AM Umbrella" Antenna on Self-supporting Tower when Situated over Perfect Earth. Tower Legs are Located at Azimuth Angles of 0, 120, and 240 degrees. Transmit Frequency is 750 kHz.

Anchor Location	Umbrella-Wire Attributes Anchor Height (ft)	Down-slope Angle (deg)	Length (Lambda)	Electric-field Strength (mV/m)
Leg	300	45	0.25	315.72, 316.24
"	"	"	0.1875	317.86, 318.03
"	"	"	0.125	318.98, 319.01
Leg	300	60	0.25	316.86, 317.13
"	"	"	0.1875	318.49, 318.56
"	"	"	0.125	318.62, 318.64
Face	300	45	0.25	313.56, 313.04
"	"	"	0.1875	315.74, 315.59
"	"	"	0.125	315.20, 315.16
Face	300	60	0.25	311.29, 311.05
"	"	"	0.1875	312.68, 312.62
"	"	"	0.125	311.92, 311.91

The field-intensity values in each row are the vertical components predicted by the computer for azimuth angles of 0 and 60 degrees, respectively, calculated at ground level at a distance of one kilometer, with a power input of one kilowatt.

Table VII. Electric-field Intensity Values for "AM Umbrella" Antenna on Self-supporting Tower with Three 8-foot Ground Rods, when Situated over Real Earth. Tower Legs are Located at Azimuth Angles of 0, 120, and 240 degrees. Transmit Frequency is 750 kHz.

Anchor Location	Umbrella-Wire Attributes Anchor Height (ft)	Down-slope Angle (deg)	Length (Lambda)	Electric-field Strength (mV/m)
Leg	300	45	0.25	192.67, 193.31
"	"	"	0.1875	199.24, 199.44
"	"	"	0.125	203.32, 203.37
Leg	300	60	0.25	189.50, 189.85
"	"	"	0.1875	198.00, 198.10
"	"	"	0.125	202.37, 202.40
Face	300	45	0.25	191.36, 190.74
"	"	"	0.1875	197.79, 197.61
"	"	"	0.125	200.82, 200.78
Face	300	60	0.25	186.01, 185.66
"	"	"	0.1875	194.23, 194.14
"	"	"	0.125	198.02, 198.00

The field-intensity values in each row are the vertical components predicted by the computer for azimuth angles of 0 and 60 degrees, respectively, calculated at ground level at a distance of one kilometer, with a power input of one kilowatt.